

1 **CENTER FREQUENCY ADJUSTMENT FOR A NOTCH FILTER**

2

3 **BACKGROUND OF THE INVENTION**

4 1. Field of the Invention

5 The present invention relates to data storage devices and, in particular, to
6 suppression of mechanical resonance, and more particularly to suppression of mechanical
7 resonance by using a notch filter.

8 2. Description of the Related Art

9 A hard disk drive widely used as an external storage device for a computer device is
10 provided with a magnetic head for reading user data stored on a magnetic disk, or for
11 writing user data on the magnetic disk. The magnetic head is attached to an actuator
12 mechanism oscillated by a voice coil motor (VCM). When reading or writing of the user
13 data is executed by the magnetic head, the actuator mechanism is driven to move and
14 position the magnetic head on a specific track (target track). The magnetic head is
15 controlled to move to a predetermined position based on servo information stored on the
16 magnetic disk.

17 In the magnetic disk such as a hard disk, a plurality of data tracks are concentrically
18 formed, and a servo track containing identification information and a burst pattern prestored
19 therein is formed along a radial direction of the magnetic disk. The identification
20 information and the burst pattern constitute the aforementioned servo information. The
21 identification information indicates a track address of each data track. Based on the

1 identification information read by the magnetic head, determination can be made as to an
2 approximate position of the magnetic head, i.e., which of the data tracks the position of the
3 magnetic head corresponds to. The burst pattern is made up of a plurality of burst pattern
4 rows in which areas storing signals are arrayed at fixed intervals along the radial direction
5 of the magnetic disk and phases of the signal storage areas are different from one another.

6 Based on a signal (position error signal: PES) outputted from the magnetic head in
7 accordance with the burst pattern, detection can be made as to a precise position of the
8 magnetic head, i.e., deviation regarding how far the position of the magnetic head deviates
9 from the corresponding data track.

10 The reading/writing of the user data with respect to the magnetic disk is executed in
11 a rotating state of the magnetic disk, after the magnetic head is moved to correspond to a
12 target track while the approximate position of the magnetic head is determined based on the
13 identification information read by the magnetic head, and then the magnetic head is
14 precisely positioned on the target track based on a signal outputted from the magnetic head
15 in accordance with a burst pattern. This series of control is referred to as seek control.

16 Additionally, even during the reading/writing of the user data, feedback control is executed
17 for the target track based on PES so that the magnetic head can follow. This series of
18 control is referred to as following control. These controls are examples of so-called servo
19 control.

20 In such servo control, for example, when a mechanism of an actuator or the like
21 mechanically resonates at a specific resonance frequency, amplitude of the resonance
22 frequency is superposed on the PES, consequently creating a problem of instability of a

1 seeking operation or a following operation of the magnetic head.

2 Thus, in the conventional hard disk drive, a notch filter of a center frequency equal
3 to a resonance frequency is inserted into a servo loop, and a gain of the resonance frequency
4 contained in a control signal is reduced by the notch filter, whereby the seeking operation
5 and the following operation are stabilized.

6 However, there are subtle individual differences among actuators, and the
7 resonance frequency varies from actuator to actuator. Additionally, in the same actuator,
8 the resonance frequency changes according to a temperature change: Now, if a resonance
9 frequency of an actuator is markedly different from a cutoff frequency band around a center
10 frequency set in the notch filter, abnormalities are exposed by inspection at the time of
11 shipping, thus creating no problems. However, if the resonance frequency of the actuator
12 deviates only slightly from the cutoff frequency band of the notch filter, it is difficult to
13 discover abnormalities by inspection at the time of shipping, creating a concern of problem
14 discovery after shipping. Recently in particular, because of narrow setting of a data track
15 width so as to increase recording density, a servo band frequency must be increased so as
16 to suppress effects of low frequency external disturbances, and effects of mechanical
17 resonance at a relatively high frequency are conspicuous.

18

SUMMARY OF THE INVENTION

20 The present invention is designed to solve the foregoing technical problems, and it
21 is an object of the invention to reduce effects of a resonance frequency of an actuator or the
22 like without a reduction in servo control performance.

1 As a measure to counter such variance or changes in the resonance frequency of the
2 actuator, the Q value of the notch filter may be set small to increase a cutoff frequency band
3 width. However, the increased cutoff frequency band width of the notch filter results in an
4 increase of a phase delay at the servo band frequency present at a frequency lower than the
5 center frequency set in the notch filter, and the phase margin of the servo loop is thus
6 reduced lowering servo control performance.

7 Therefore, the inventors have discovered that instead of increasing the cutoff
8 frequency band width of the notch filter, the cutoff frequency itself should preferably be
9 matched with a resonance frequency of an actual mechanical system to be actively changed,
10 which has led to the present invention.

11 The data storage device of the present invention includes: an actuator for supporting
12 and moving a head for reading/writing data on a recording medium; a servo control unit for
13 feeding back a position error signal obtained by scanning the recording medium by the head
14 to control an operation of the actuator; a notch filter for reducing the gain of a preset center
15 frequency component from a servo signal transmitted from the servo control unit; deviation
16 detecting means for detecting deviation of a resonance frequency of the actuator from a
17 center frequency set in the notch filter; and changing means for changing a set value of the
18 center frequency set in the notch filter based on a result of the deviation detection by the
19 deviation detecting means.

20 In this case, the deviation detecting means preferably has a band-pass filter for
21 passing a center frequency component corresponding to the resonance frequency from the
22 servo signal transmitted from the servo control unit, a phase shifter for receiving a signal

1 containing the resonance frequency as an input, and for shifting a phase at the resonance
2 frequency of the signal by a predetermined amount, and a multiplier for multiplying the
3 signal passed through the band-pass filter by the signal passed through the phase shifter.

4 Moreover, preferably, the deviation detecting means further has an averaging unit for
5 averaging output results of multiplication by the multiplier.

6 Additionally, the phase shifter preferably includes an all pass filter for generating a
7 predetermined phase delay of 90 degrees.

8 Furthermore, the changing means preferably shifts the center frequency set in the
9 notch filter to a low frequency side when a multiplication result by the multiplier exceeds a
10 predetermined value, and to a high frequency side when the multiplication result by the
11 multiplier drops below the predetermined value.

12 Then, preferably, the notch filter includes an all pass filter for passing the servo
13 signal transmitted from the servo control unit, and a first adder for adding the signal passed
14 through the all pass filter and the servo signal not passed through the all pass filter, and the
15 band-pass filter includes the all pass filter, and a second adder for adding a negative value
16 of the signal passed through the all pass filter and the servo signal not passed through the all
17 pass filter.

18 The present invention can be understood as a program for causing a computer to
19 realize: a function of extracting a resonance frequency of a structure contained in a servo
20 signal; a function of detecting deviation of the resonance frequency from a center frequency
21 set in a notch filter; and a function of shifting the center frequency of the notch filter to the
22 resonance frequency side.

1 In this case, preferably, the function of extracting the resonance frequency of the
2 structure contained in the servo signal passes the servo signal through a band-pass filter.
3 The function of detecting the deviation of the resonance frequency from the center
4 frequency set in the notch filter multiplies a signal of the extracted resonance frequency by
5 a delay signal delaying a phase of the servo signal by 90 degrees, and the function of
6 shifting the center frequency of the notch filter to the resonance frequency side shifts the
7 center frequency set in the notch filter to a low frequency side when an output of the
8 function of detecting deviation exceeds a predetermined value, and to a high frequency side
9 when the output drops below the predetermined value.

10 Additionally, the function of detecting the deviation of the resonance frequency
11 from the center frequency set in the notch filter averages output results of multiplication
12 after the multiplication of the signal of the extracted resonance frequency by the delay
13 signal delaying the phase of the servo signal by 90 degrees.

14 To cause the computer to execute the aforementioned functions, a program is stored
15 in a storage medium to be read by the computer. The storage medium may be, for example
16 a CD-ROM medium or the like. The program is read by a CD-ROM reader in the computer
17 and, for example, a mode of the program stored in a hard disk drive or the like in the
18 computer and may be executed.. Additionally, for the programs, for example, a mode
19 provided to a notebook PC or a portable terminal by a program transmitter through a
20 network is conceivable. As such a program transmitter, it is only necessary for the
21 transmitter to be provided with a memory for storing the program, and program transmitting
22 means for providing the program through the network.

Furthermore, the present invention describes a method of carrying out the aforementioned functions of the program.

3

4 BRIEF DESCRIPTION OF THE DRAWINGS

5 For a more complete understanding of the present invention and the advantages
6 thereof, reference is now made to the following description taken in conjunction with the
7 accompanying drawings.

8 Fig. 1 is a block diagram showing main sections of a hard disk drive according to a
9 first embodiment.

Fig. 2 is an explanatory view showing a storage surface of a magnetic disk.

Fig. 3 is an explanatory view showing a filter circuit used in the first embodiment.

12 Figs. 4(a) and 4(b) are graphs respectively showing a frequency-gain characteristic
 13 of an APF, and a frequency-phase characteristic of the APF.

Fig. 5 is a graph showing a frequency-phase characteristic of another APF.

15 Fig. 6 is a graph showing a frequency-gain characteristic of a notch filter comprising
16 an APF and a first adder.

17 Fig. 7 is a graph showing a frequency-gain characteristic of a band-pass filter
18 comprising an APF and a second adder.

Fig. 8 is a graph showing a frequency-phase characteristic of the band-pass filter comprising the APF and the second adder.

Fig. 9 is a graph showing a frequency-output voltage characteristic of a multiplier.

Fig. 10 is a flowchart showing a feedback control process by the filter circuit and a

1 servo controller.

2 Fig. 11 is an explanatory view showing a filter circuit used in a second embodiment.

3

4 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

5 **First embodiment**

6 Fig. 1 is a block diagram showing main sections of a hard disk drive 1 according to

7 a first embodiment. The hard disk drive 1 has a magnetic disk 2, a spindle motor 3, a

8 magnetic head 4, an actuator 5, a voice coil motor (VCM) 6, a digital/analog converter

9 (DAC) 7, a VCM driver 8, a filter circuit 9, a read/write circuit 11, a micro processing unit

10 (MPU) 12, a hard disk controller (HDC) 13, and a read only memory (ROM) 14. The hard

11 disk drive 1 is connected through the HDC 13 to a host computer (HOST) 30. The hard

12 disk drive 1 is a storing/reproducing device in which the magnetic head 4 seeks on the

13 magnetic disk 2 rotary-driven by the spindle motor 3 and stays on a predetermined track

14 (target track) to write data on the magnetic disk 2 or read data written on the magnetic disk

15 2. A single or a plurality of magnetic disks 2 are loaded as necessary. An example of a

16 single magnetic disk 2 is shown in Fig. 1.

17 While the hard disk drive 1 is operating, the magnetic disk 2 is rotated on a spindle

18 shaft of the spindle motor 3, and its rotation is stopped (stationary) when the hard disk drive

19 1 is not operating.

20 Two magnetic heads 4 are held on a tip of the actuator 5 to access the front and back

21 surfaces of the magnetic disk 2. The magnetic head 4 writes/reads data to or from the

22 magnetic disk 2. The magnetic head 4 also reads servo information stored on the magnetic

1 disk 2. The servo information will be described later. The magnetic head 4 is moved in a
2 radial direction on the magnetic disk 2 integrally with the actuator 5. A ramp (not shown)
3 for unloading from the disk when the magnetic head 4 is not driven is disposed outside the
4 magnetic disk 2.

5 The actuator 5 is driven by the VCM 6. Accordingly, it can be said that the VCM 6
6 drives the magnetic head 4. The VCM 6 comprises a rotor using a coil as an element, and a
7 stator using a permanent magnet as an element. Predetermined current is supplied from the
8 VCM driver 8 to the coil to drive the rotor, whereby the magnetic head 4 is moved toward
9 the target track on the magnetic disk 2. The actuator 5 has a resonance frequency of 10500
10 Hz in a normal state.

11 The read/write circuit 11 executes data reading/writing. That is, write data
12 transferred from the HOST 30 through the HDC 13 is converted into a write signal (current)
13 to be supplied to the magnetic head 4. The magnetic head 4 writes data on the magnetic
14 disk 2 based on the write current. On the other hand, a read signal (current) read from the
15 magnetic disk 2 is converted into digital data to be outputted through the HDC 13 to the
16 HOST 30. The digital data contains servo information.

17 The HDC 13 has interface functions to the hard disk drive 1. As one of such
18 functions, the write data transferred from the HOST 30 is received, and also transferred to
19 the read/write circuit 11. Additionally, the read data transferred from the read/write circuit
20 11 is transferred to the HOST 30. Furthermore, a command or the like is received from the
21 HOST 30 to transfer the read data to the MPU 12.

22 The MPU 12 controls the hard disk drive 1. The MPU 12 has a function as a servo

1 controller 12a, and also executes movement control of the magnetic head 4, in other words,
2 seek control or following control. The MPU 12 interprets and executes a program stored in
3 the ROM 14. The MPU 12 (servo controller 12a) determines a position of the magnetic
4 head 4 based on the servo information transferred from the read/write circuit 11, and
5 outputs a speed control value of the magnetic head 4 to the DAC 7 based on deviation of
6 the determined position of the magnetic head 4 with respect to a target position. The speed
7 control value as a movement command of the magnetic head 4 is outputted for each reading
8 of the servo information by the magnetic head 4.

9 The DAC 7 converts the speed control value outputted from the magnetic head 4
10 into an analog signal (voltage signal), and outputs it to the VCM driver 8.

11 The VCM driver 8 converts the voltage signal received from the DAC 7 into driving
12 current, and supplies it to the VCM 6.

13 The filter circuit 9 has a function of reducing a gain of a resonance frequency of the
14 actuator 5 contained in the speed control value, and passes the speed control value of the
15 reduced gain of the resonance frequency of the actuator 5 to the DAC 7. The filter circuit 9
16 also has a function of detecting a difference between the set resonance frequency of the
17 actuator 5 and an actual resonance frequency, and feeds back a detected value to the MPU
18 12 (servo controller 12a). The filter circuit 9 will be described in detail later.

19 The HOST 30 has a disk drive 30a for reading a program or data recorded in a disk
20 medium such as a CD-ROM or a DVD read only memory (DVD-ROM), and a network
21 interface (NI/F) 30b for communicating with an external network or downloading various
22 programs.

1 Fig. 2 shows a storage surface (one surface side) of the magnetic disk 2. On the
2 surface of the magnetic disk 2, a plurality of position information (servo information)
3 storage areas 20 are radially formed along the radial direction of the magnetic disk 2, and
4 data storage areas 21 are formed in other areas. Fig. 2 shows three position information
5 storage areas 20 and data storage areas 21 held therebetween. However, actually, many
6 more position information areas 20 and data storage areas 21 are formed in a
7 circumferential direction of the magnetic disk 2. The servo information stored in the
8 position information storage area 20 is read by the magnetic head 4, whereby a position of
9 the magnetic head 4 is determined. The servo information comprises track identification
10 data and a burst pattern. The track identification information indicates a track address of
11 each data track. The track identification information is read by the magnetic head 4,
12 whereby a track position in which the magnetic head 4 is currently located can be
13 determined. The burst pattern has areas storing respective signals arrayed at fixed intervals
14 along the radial direction of the magnetic disk 2, and comprises a plurality of signal storage
15 area rows in which phases of signal storage areas are different from one another. Based on
16 a signal outputted from the burst pattern, it is possible to determine the amount of deviation
17 of the magnetic head 4 with respect to the data track.

18 Fig. 3 specifically shows the filter circuit 9. This filter circuit 9 has an all pass filter
19 (APP) 31 to which a speed control value u outputted from the servo controller 12a is
20 entered, and a first adder 32 for adding the speed control value u from the servo controller
21 12a and an APP passed signal v passed through the first APP 31. An output $f(n)$ of the first
22 adder 32 is outputted as a speed control value to the DAC 7. Incidentally, the speed control

1 value u is a value set by the servo controller 12a based on the servo information read by the
2 magnetic head 4, and is a current value for controlling the moving speeds of actuator 5 and
3 the magnetic head 4 attached thereto.

4 Additionally, the filter circuit 9 has a second adder 33 for adding the speed control
5 value u and a negative component -v of the APF passed signal v passed through the first
6 APF 31, a second APF 34 to which the speed control value u is entered, a multiplier 35 for
7 multiplying an output y(n) of the second adder 33 by an output p(n) of the second APF 34,
8 an averaging unit 36 for averaging outputs a(n) of the multiplier 35, and a RAM 37 for
9 temporarily storing past outputs a(n-1), a(n-2)... of the multiplier 35. The output a(n) of the
10 averaging unit 36 is fed back to the servo controller 12a.

11 Figs. 4(a) and 4(b) are graphs respectively showing a frequency-gain characteristic
12 of the first APF 31, and a frequency-phase characteristic of the first APF 31. In the
13 embodiment, the APF 31 is a digital filter. In the APF 31, as clearly seen from Figs. 4(a)
14 and 4(b), a gain with respect to a frequency is roughly constant, while a phase with respect
15 to the frequency is changed from 0 to -360 degrees as a function of frequency. The APF 31
16 outputs an output v having a phase delay of 180 degrees generated with respect to the speed
17 control value u at a center frequency fc. A transmission function H(z) of the APF 31 is
18 represented by the following equation:

19 Equation 1:

$$20 \quad H(z) = \frac{a_2 z^2 + a_1(1+a_2)z + 1}{z^2 + a_1(1+a_2)z + a_2}$$

21

22 where,

1 $a_1 = -\cos(\omega_0 T_s)$

2 ω_0 : center frequency

3 T_s : sampling time

4 In the embodiment, the center frequency fc of the APF 31 can be varied and, in an

5 initial state, it is set to 10500 Hz equal to the normal resonance frequency of the actuator 5

6 (see Fig. 1).

7 Fig. 5 is a graph showing a frequency-phase characteristic of the second APF 34. In

8 the embodiment, the second APF 34 is also a digital filter. A frequency of the second APF

9 34 generating a phase delay of 90 degrees is set to 10500 Hz equal to the center frequency

10 of the first APF 31. That is, in the embodiment, the second APF 34 is operated as a phase

11 shifter for shifting a phase.

12 In Fig. 3, the first adder 32 adds the speed control value u from the servo controller

13 12a and the APF passed signal v passed through the APF 31. As shown in Fig. 4(b), the

14 APF passed signal v has a phase delay of 180 degrees generated with respect to the speed

15 control value u at a cutoff frequency fc (10500 Hz). Accordingly, a frequency-gain

16 characteristic of an output $f(n)$ from the first adder 32 becomes, as shown in Fig. 6, one

17 having a notch formed in which 10500 Hz is set as a center frequency and a frequency

18 component around it is also reduced slightly. That is, the first APF 31 and the first adder 32

19 constitute a notch filter having 10500 Hz set as a center frequency. Thus, the speed control

20 value u outputted from the servo controller 12a is outputted to the DAC 7 in a state where a

21 gain at a frequency (corresponding to the resonance frequency of the actuator 5) in the

22 vicinity of 10500 Hz is reduced by the notch filter. A transmission function $H(z)$ of the

1 notch filter is represented by the following equation. Incidentally, Fig. 6 shows a relation
2 when sampling time is 39.68 microseconds, and $a_2=0.88205$.
3 Equation 2:

4
$$H(z) = \frac{1}{2}(1+a_2) \frac{z^2 + 2a_1z + 1}{z^2 + a_1(1+a_2)z + a_2}$$

5 The second adder 33 adds the speed control value u from the servo controller 12a
6 and the negative component $-v$ of the APF passed signal v passed through the first APF 31.
7 In other words, a difference between the speed control value u and the APF passed signal v
8 is calculated. As shown in Fig. 4(b), the APF passed signal v has a phase delay of 180
9 degrees generated with respect to the speed control value u at the cutoff frequency f_c
10 (10500 Hz). Accordingly, a frequency-gain characteristic of an output $y(n)$ from the second
11 adder 33 becomes, as shown in Fig. 7, one having a peak formed in which 10500 Hz is set
12 as a center frequency, and a frequency component around it is also passed a little. A
13 frequency-phase characteristic of the output $y(n)$ has, as shown in Fig. 8, a feature that an
14 advance delay of the phase disappears at 10500 Hz, the phase advances at a frequency
15 below 10500 Hz, and the phase delays at a frequency exceeding 10500 Hz. That is, the first
16 APF 31 and the second adder 33 comprise a band-pass filter having 10500 Hz set as a
17 center frequency. Accordingly, the speed control value u outputted from the servo
18 controller 12a is outputted to the multiplier 35 in a state where only a frequency
19 (corresponding to the resonance frequency of the actuator 5) in the vicinity of 10500 Hz is
20 passed by the band-pass filter.

21 Furthermore, the multiplier 35 multiplies the output $y(n)$ of the second adder 33 by

1 the output $p(n)$ of the second APF 34. As shown in Fig. 5, the output $p(n)$ of the second
2 APF 34 has a phase delay of 90 degrees generated with respect to the speed control value u
3 at the frequency of 10500 Hz.

4 Therefore, when a gain of the band-pass filter comprising first APF 31 and the
5 second adder 33 is X , a phase at this time is Y , a phase delay by the second APF 34 is $Z-\pi$
6 /2, and an input to the band-pass filter is $\sin(\omega t)$, then the output $y(n)$ of the band-pass filter
7 becomes

8 $y(n) = X \sin(\omega t + Y),$

9 the output $p(n)$ of the second APF 34 becomes

10 $p(n) = \sin(\omega t + Z - \pi/2) = -\cos(\omega t + Z),$

11 and a product $a(n)$ thereof becomes

12 $a(n) = -X/2 \{ \sin(Y - Z) + \sin(2\omega t + Y + Z) \}..$

13 A DC component in this case is decided by the gain of the band-pass filter and the phase of
14 the second APF 34. Thus, voltage $a(n)$ outputted from the multiplier 35 is, as shown in Fig.
15 9, 0 at a frequency of 10500 Hz, negative at a frequency below 10500 Hz, and positive at a
16 frequency exceeding 10500 Hz. That is, the voltage $a(n)$ exhibits a negative value when a
17 real resonance frequency of the actuator 5 is below 10500 Hz, and a positive value when a
18 real resonance frequency of the actuator exceeds 10500 Hz.

19 Furthermore, the averaging unit 36 calculates an average among past output voltages
20 $a(n-1), a(n-2)...$ of the multiplier 35 accumulated in the RAM 37 and currently outputted
21 output voltage $a(n)$, and outputs it as an average output $a(n)$. In the embodiment, an
22 average value $a(n)$ is calculated based on the past five output voltages $a(n-1)$ to $a(n-5)$ and

1 the current output voltage $a(n)$.

2 Fig. 10 is a flowchart showing a feedback control process by the filter circuit 9 and

3 the servo controller 12a.

4 First, at the first APF 31, servo sampling is executed at a predetermined timing (step

5 S101), and then an output $y(n)$ is calculated by the band-pass filter (comprising the APF 31

6 and the second adder 33) (step S102).

7 Subsequently, a value sampled in step S101 is entered to the second APF 34, an

8 output $p(n)$ is calculated at the second APF 34 (step S103), and $a(n)$, i.e., $p(n) \times y(n)$ is

9 calculated by the multiplier 35 (step S104).

10 Furthermore, an average output $a(n)$ is calculated based on the output $a(n)$ and the

11 past outputs $a(n-1)$ to $a(n-5)$ stored in the RAM 37 (step S105).

12 Then, when the average output $a(n)$ is returned to the servo controller 12a, first,

13 determination is made as to whether the average output $a(n)$ is larger than 0.1 (V) or not

14 (step S106). If the average output $a(n)$ is determined to be larger than 0.1 (V), a control

15 signal is sent to the first APF 31 so as to shift a center frequency of the APF 31 comprising

16 the notch filter to a low frequency side by a predetermined value (e.g., 10 Hz) (step S107),

17 and the process returns to step S101.

18 On the other hand, if the average output $a(n)$ is determined to be smaller than 0.1 V

19 in step S106, determination is then made as to whether the average output $a(n)$ is smaller

20 than -0.1 V or not (step S108). If the average output $a(n)$ is determined to be smaller than

21 -0.1 V, a control signal is sent to the first APF 31 so as to shift a center frequency of the

22 APF 31 comprising the notch filter to a high frequency side by a predetermined value (e.g.,

1 10 Hz) (step S109), and then the process returns to step S101. If the average output a(n) is
2 determined to be larger than -0.1 V in step S108, the process directly returns to step S101
3 without changing the center frequency of the APF 31 comprising the notch filter.

4 According to the embodiment, the band-pass filter comprising the APF 31 and the
5 second adder 33, the second APF 34, and the multiplier 35 are used to detect how much the
6 current resonance frequency of the actuator 5 deviates from the set value of the center
7 frequency of the first APF 31. Based on this detected result, the center frequency of the
8 APF 31 is properly adjusted. The adjustment of the center frequency of the APF 31 enables
9 the center frequency set in the notch filter comprising the APF 31 and the first adder 32 to
10 be automatically approximated to the current resonance frequency of the actuator 5. Thus,
11 even if fluctuation occurs in the resonance frequency of the actuator 5 for any reason, the
12 gain at the resonance frequency of the actuator 5 contained in the speed control value u can
13 be reduced by the notch filter of the adjusted center frequency to be outputted to the DAC 7,
14 whereby a reduction in the servo control performance can be suppressed.

15 Additionally, according to the embodiment, since the average value a(n) among the
16 output $a(n)$ from the multiplier 35 and the past outputs $a(n-1)$ to $a(n-5)$ is fed back to the
17 servo controller 12a, it is possible to reduce errors in servo control.

18 Furthermore, since the aforementioned adjusting operation of the resonance
19 frequency and the center frequency is executed in the background of the actual operation,
20 the necessity of specially setting execution time of frequency adjustment can be
21 advantageously eliminated.

22 Incidentally, according to the embodiment, the servo controller 12a is incorporated

1 in the MPU 12, and the filter circuit 9 is separate from the MPU 12 (and servo controller
2 12a). However, the design is not limited to this, and the filter circuit 9 may be incorporated
3 as one of the functions of the MPU 12.

4 Additionally, according to the embodiment, the first APF 31, the second APF 34 or
5 the like comprise digital filters. However, there are no limitations in this regard, and the
6 APF 31 and APF 34 may comprise analog filters. According to the embodiment, the input
7 to the APF 34 is the speed control value u . However, the input is not limited to this value,
8 and a similar result can be obtained in the case of the output $y(n)$ from the band-pass filter.

9 Furthermore, the embodiment has been described by way of example of a hard disk
10 drive 1. However, the invention is not limited to this, and it can be similarly applied to, for
11 example a data storage device such as an optical disk drive for reading/writing data in an
12 optical disk (corresponding to the recording medium) by using an optical pickup
13 (corresponding to the head) attached to the actuator 5.

14 Moreover, the embodiment has been described by way of example of the reduction
15 in the gain at the resonance frequency of the actuator 5. However, the invention is not
16 limited to this, and similar technique can be applied to a case of reducing effects of a
17 resonance frequency of other structures comprising the hard disk drive 1.

18

19 **Second embodiment**

20 Fig. 11 shows a filter circuit 9 according to a second embodiment. This
21 embodiment is roughly similar to the first embodiment, but different in that a notch filter
22 and a band-pass filter are individually formed instead of realizing the notch filter and the

1 band-pass filter by all pass filters (APF) and adders. Portions of the embodiment similar to
2 those of the first embodiment are denoted by the same reference numerals as those of the
3 first embodiment, and detailed description will be omitted.

4 The filter circuit 9 according to the embodiment is provided with a notch filter (NF)
5 circuit 40 having an NF 41, a band-pass filter (BPF) 51, an all pass filter (APF) 52, a
6 multiplier 53, an averaging unit 54, and a BPF circuit 50 having a RAM 55. Then, an
7 output of the NF circuit 40 is connected to a DAC 7 (see Fig. 1), and an output of the BPF
8 circuit 50 is fed back to a servo controller 12a.

9 According to the embodiment, detection is made by the BPF circuit 50 as to how
10 much a current resonance frequency of the actuator 5 (see Fig. 1) deviates from a set value
11 of a center frequency in the NF 41, and the center frequency of the NF 41 in the NF circuit
12 40 is properly adjusted based on a result of the detection, whereby it can be automatically
13 approximated to the current resonance frequency of the actuator 5, similarly to the first
14 embodiment. Accordingly, even if fluctuation occurs in the resonance frequency of the
15 actuator 5 for any reason, at the NF 41 of the adjusted center frequency, a gain at the
16 resonance frequency of the actuator 5 contained in a speed control value u can be reduced to
17 be outputted to the DAC 7. Therefore, it is possible to suppress a reduction in servo control
18 performance.

19 As described above, according to the present invention, it is possible to reduce the
20 effects of a resonance frequency of an actuator or the like without reduction in the servo
21 control performance.

22 Although the preferred embodiments of the present invention have been described

1 in detail, it should be understood that various changes, substitutions and alterations can be
2 made therein without departing from spirit and scope of the invention as defined by the
3 appended claims.

4